A New Method for Reporting and Interpreting Textural Composition of Spawning Gravel

Fredrick B. Lotspeich and Fred H. Everest

Abstract

A new method has been developed for collecting, sorting, and interpreting gravel quality. Samples are collected with a tri-tube freeze-core device and dry-sorted using sieves based on the Wentworth scale. An index to the quality of gravel is obtained by dividing geometric mean particle size by the sorting coefficient (a measure of the distribution of grain sizes) of a sample. The resulting number is called the "fredle index" and is proposed as a standard for evaluating the reproductive potential of spawning gravel.

Keywords: Spawning beds, gravels, sediment sampling, stream habitat management, indexes (spawning gravel), fish habitat.

Introduction

Fishery biologists have recognized for nearly 60 years that textural composition of spawning gravel influences survival and emergence of salmonid embryos. Harrison (1923) was one of the first to report an inverse relationship between the quantity of sand and silt in redds and the survival of incubating salmonid eggs. Subsequently there have been many studies on this subject, but fishery biologists have neither developed nor utilized a standard method of reporting textural composition of spawning gravel. Consequently, many noncomparable results and techniques have been reported in the literature. This is unfortunate since a standard method developed by earth scientists for reporting such data has been available since the mid-1930's (e.g., Krumbein and Pettijohn 1938).

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Recently we investigated the extent to which fine sediments are removed from redds by hydraulic forces created by spawning salmonids. As a result of this work, we developed a standard method to present and interpret the results of the study. We also developed a new gravel quality index which we believe is superior to indexes currently used for assessing gravel quality, such as percent fines (Phillips et al. 1975) and geometric mean (Shirazi and Seim 1979). Our objective in this paper is to describe our methods and gravel quality index and suggest how these techniques will help biologists to classify, compare, and monitor the suitability of sediments for salmonid reproduction.

Sediment texture does not control survival-to-emergence of salmonid embryos. It is the influence of texture on two fundamental properties of spawning gravels--pore size and permeability--that influences survival. Our procedure uses a measure of the central tendency of the distribution of sediment particle sizes in a sample, and the dispersion of particles in relation to the central valve, to characterize the suitability of gravels for salmonid reproduction. These two parameters are combined to derive a quality index based on permeability and an estimate of pore size. Central tendency is the geometric mean which is the diameter value that divides the frequency distribution curve into two equal areas (Inman 1952). We also chose pore size, rather than porosity, as a component of the quality index because pore size (and permeability) is directly proportional to mean grain size. Porosity, on the other hand, was shown by Graton and Frazer (1935) to be independent of grain size. Pore size and permeability regulate intragravel water velocity and oxygen transport to incubating salmonid embryos and control intragravel movement of alevins. These two substrate parameters legislate survival-to-emergence of salmonid embryos.

Collection and Analysis of Samples

The distribution of stream sediments is ordered largely by stream energy, hydraulics, and physical characteristics of a watershed, hence is nonrandom. Therefore, statistical theory based on random events may not correctly describe the composition of stream sediments. Streams used by spawning salmonids usually consist of a succession of riffles and pools whose positions remain relatively constant over time despite wide fluctuations in streamflow. Texture in a given reach of stream is a function of stream mechanics governed by climate (quantity and intensity of rainfall) and geology (lithology, structure, and geomorphology), a cause-and-effect relationship which can be modeled. It is not a strictly stochastic phenomenon but usually results from episodic events caused by regional meteorology.

Selection of spawning sites by salmonids is also a nonrandom activity. Adult salmonids selecting locations to spawn respond to environmental releasers such as water depth and velocity, substrate composition, and proximity to cover. Because both sediment distribution and redd site selection are nonrandom events, the location from which samples are drawn to characterize spawning gravels should be identified by an experienced fishery biologist. Samples should only be drawn from locations that meet the known spawning requirements of a species. The suitability of each sampling site should be determined by quantitative measurements of water depth and velocity. The depth at which the sample is extracted is also critical to the analysis. Samples should be taken only as deep as the average depth of egg deposition for the species being studied. Since there is substantial stratification in stream gravels, sampling above or below the level of egg deposition might yield an inaccurate estimate of the size and distribution of grains within a redd.

All of our samples were drawn using the liquid CO_2 procedure first described as a working tool by Walkotten (1976) and later modified by Everest et al. (1980) and Lotspeich and Reid (1980). Using this procedure we can detect and measure redd stratigraphy and determine the texture of individual subsamples. Our textural analysis uses the dry sieve technique based on the Wentworth scale with a geometric progression of 12 size-classes ranging from 0.062 to 100 mm (0.002 to 3.94 in). The upper limit might seem arbitrary, but it approximates the largest size particles in which most salmonids will spawn. Consequently, few grains larger than 100 mm are present in preferred spawning areas.

Textural composition of a redd may be presented in graphic form for easy interpretation (Lotspeich 1978) (fig. 1). Depending on the distribution of sediments and the needs of the analysis, the y-axis of the graph can be scaled with arithmetic, probability, or logarithmic units. Geometric mean (d_g) of a sample is calculated by raising the grain size at the midpoint of each class to a power equal to the decimal fraction of its weight, then multiplying the products of each class to obtain a final product which is d_g provided that 100 percent of the sample is used (see equation 1). Calculation of d_g is easily done with electronic calculators or computers.

$$d_g = [d_1{}^{w1} \times d_2{}^{w2} \ldots\ldots\ldots\ldots \times d_n{}^{w}n] \tag{1}$$

where

d_g = geometric mean particle size.

d = midpoint diameter of particles retained by a given sieve.

w = decimal fraction by weight of particles retained by a given sieve.

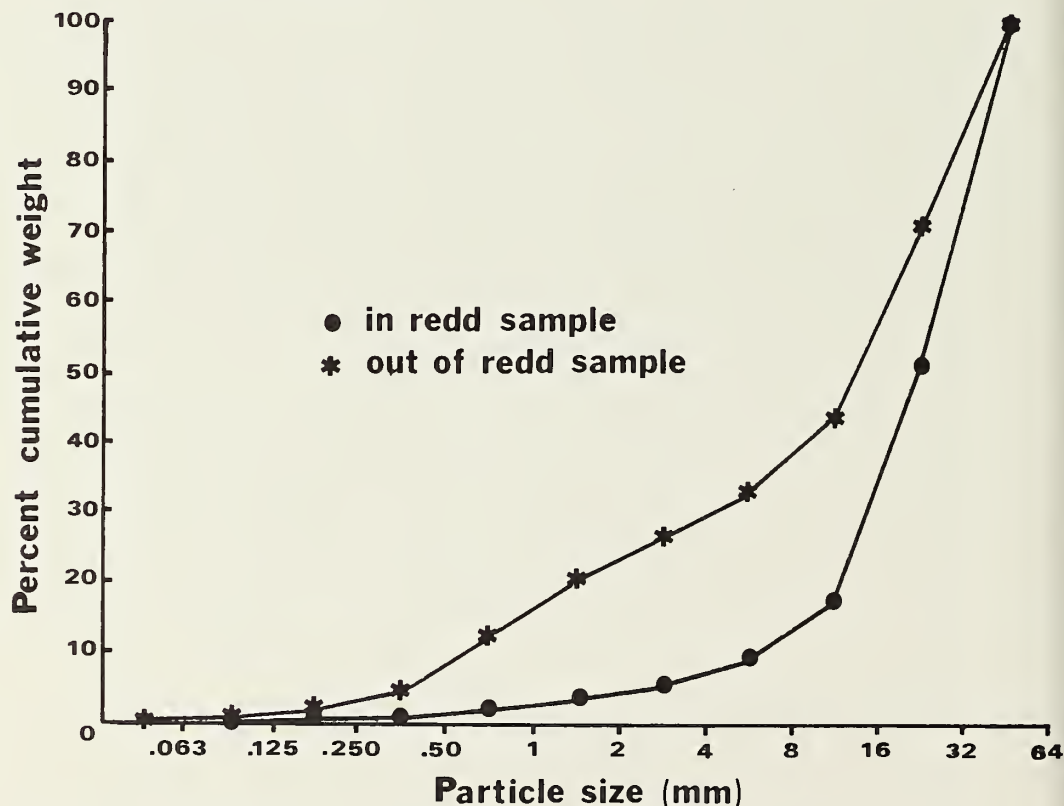Figure 1.--Graphical comparison of sediment texture within and adjacent to a chinook salmon (Oncorhynchus tshawytscha (Walbaum)) redd (Evans Creek, Oregon).

Other workers (Shirazi and Seim 1979) used d_g to describe the
central tendency of sediment particle size. Shirazi and Seim
(1979), however, suggest using only two points on the distri-
bution curve (d_{16} and d_{84}) to calculate d_g. Such action
does not fully consider small size-classes that strongly influence
pore size, permeability, and reproductive potential of spawning
gravel. Their procedure is based on the assumption that grains
in a gravel bed are deposited randomly and that d_{16} and d_{84}
adequately describe d_g. Our data do not support this
assumption. For example, we collected 400 gravel samples from
the Rogue River basin, and 30 were found to have a d_g of 10 mm
(0.39 in) using equation (1) which considers all particles in
each sample. Geometric mean was then recalculated for each
sample using Shirazi and Seim's (1979) two-point method
($d_g = \sqrt{d_{16} \times d_{84}}$), and a wide spread of values was obtained.
Sample d_g's ranged from 4.9 to 11.8 mm (0.19 to 0.46 in) with a
mean of 6.2 mm (0.24 in). Therefore, we believe that all size-
classes in a sample should be used in calculating d_g.

Despite its essential role in describing sediments, d_g alone is
inadequate to estimate the quality of gravel for salmonid repro-
duction. Gravel mixtures with a common d_g can have wide
variation in fine sediment content. Figure 2 illustrates three
gravel mixtures with equal d_g of 12 mm (0.47 in) that have 0-,
15-, and 30-percent sediment <1 mm (<0.039 in) in diameter,
respectively. Since survival-to-emergence of salmonids is
directly related to fine sediment content in gravels (Phillips et
al. 1975), use of d_g as the sole index to gravel quality could
easily lead to erroneous predictions of survival. Similar
problems can occur when using percent fines less than a specified
diameter to estimate gravel quality.
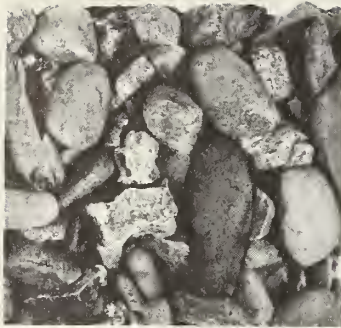
top view

MIX 2	
GEOMETRIC MEAN	=12.00
SORTING COEFFICIENT	= 3.40
FREDLE INDEX	= 3.53
% FINE SEDIMENT <1 mm DIAMETER	= 15%
PREDICTED EMERGENCE OF COHO	= 51%

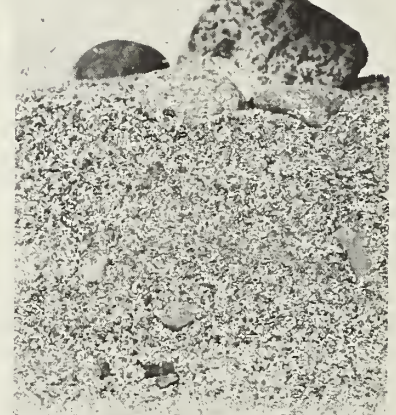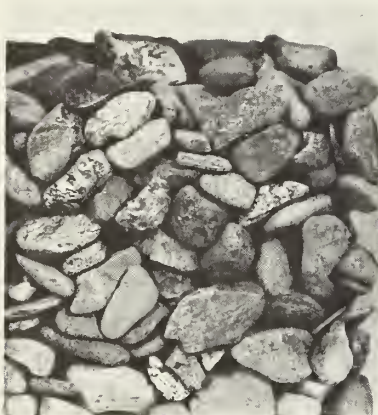| MIX 3	
GEOMETRIC MEAN	=12.00
SORTING COEFFICIENT	= 7.61
FREDLE INDEX	= 1.58
% FINE SEDIMENT <1 mm DIAMETER	= 30%
PREDICTED EMERGENCE OF COHO	22%

side view

Figure 2.--Three gravel mixtures with a common geometric mean (d_g) but widely divergent distribution of particle sizes.

In addition to d_g, the size distribution of sediment particles in a sample is a useful descriptor of a gravel's reproductive potential for salmonids. Permeability and pore size, which control movement of water and alevins through gravel, are determined largely by the size distribution of grains in a sample. To quantify the distribution of grain sizes in gravels, we have used the sorting coefficient described by Krumbein and Pettijohn (1938). S_O is derived by taking the square root of the quotient of the grain size at the 75th percentile divided by that at the 25th percentile. Our choice of the 25- to 75-percent interval is based on the premise that 50 percent of the grains in a sample provide a reliable index of sediment sorting. Other intervals have been chosen to perform the same calculation, 16 to 84 percent for example (Shirazi and Seim 1979).

By definition of Krumbein and Pettijohn (1938), a perfectly sorted gravel (with only one grain size) will have an S_O of 1. All imperfectly sorted gravels will have an S_O greater than unity. A sorting coefficient greater than 1 implies that pores between large grains are filled with smaller grains that impede permeability, hence S_O is inversely proportional to permeability. Thus we have two parameters, d_g which is directly proportional to pore size and permeability, and S_O, a measure of the distribution of grain sizes in gravels, which is inversely proportional to permeability. We propose the use of a ratio of these numbers called the "fredle index" (f_i), where $f_i = \dfrac{d_g}{S_O}$, as a measure of the quality of riffle gravels for salmonid reproduction.

Fredle numbers for a sediment with one grain size will be equal to the geometric mean because S_O is then 1. Sediments with the same d_g will have f_i numbers less than the mean as S_O increases. The samples in figure 2 which have a common d_g of 12 mm (0.47 in) yield fredle numbers of 12.00, 3.53, and 1.58, respectively (table 1). Sediments with small d_g are less permeable than those with larger means because pores are small and intragravel flow and movement of alevins is impeded even though S_O might be 1. Also, sediments with large d_g might be slowly permeable when S_O is large because pore spaces are occupied with smaller grains that impede interstitial flow and movement. Thus, the magnitude of fredle numbers is a measure of both pore size and relative permeability, both of which increase as the index number becomes larger.

Table 1—Characteristics of artificial gravel mixtures used as examples

Particle diameter	Mix 1 0 percent fine sediment less than 1-millimeter diameter	Mix 2 15 percent fine sediment less than 1-millimeter diameter	Mix 3 30 percent fine sediment less than 1-millimeter diameter
Millimeters			
32-60	--	45	60
16-32	--	15	10
8-16	100	10	--
4-8	--	5	--
2-4	--	5	--
1-2	--	5	--
0.5-1.0	--	5	20
.25-.50	--	5	10
.125-.25	--	5	--
d_g[1] = 12.00		12.00	12.00
S_o[2] = 1.00		3.40	7.61
f_i[3] = 12.00		3.53	1.58
Percent predicted survival of coho salmon[4] = 98		51	22

[1] d_g = geometric mean particle size.

[2] S_o = sorting coefficient.

[3] f_i = fredle index ($f_i = \dfrac{d_g}{S_o}$).

[4] From Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish Soc. 104(3):461-466.

The relationship between f_i numbers and survival-to-emergence of salmonid alevins has not been documented experimentally. We have used the data of Phillips et al. (1975), however, to establish a preliminary relationship between these parameters. Phillips et al. (1975) examined survival-to-emergence of coho salmon (Oncorhynchus kisutch (Walbaum)) and steelhead trout (Salmo gairdneri Richardson) embryos in gravel mixtures of known composition. We have calculated fredle numbers for the mixtures of Phillips et al. and plotted them against survival (fig. 3). The preliminary relationship indicates that the fredle index is responsive to slight changes in gravel composition, survival, and variations in intragravel habitat requirements of individual species. For example, in Phillips et al.'s artificial gravels with f_i of 2, 4, and 8, survival-to-emergence of 30, 60, and 88 percent, respectively, can be predicted for coho salmon, while survival of steelhead trout can be predicted at 45, 75, and 99 percent in the same mixtures. The difference between survival of coho and steelhead at a given f_i is probably related to differences in the cranial diameter of alevins which controls their movement through pore spaces in gravel. Our next task is to develop relationships between fredle numbers and survival-to-emergence of salmonid embryos from natural gravel mixtures.
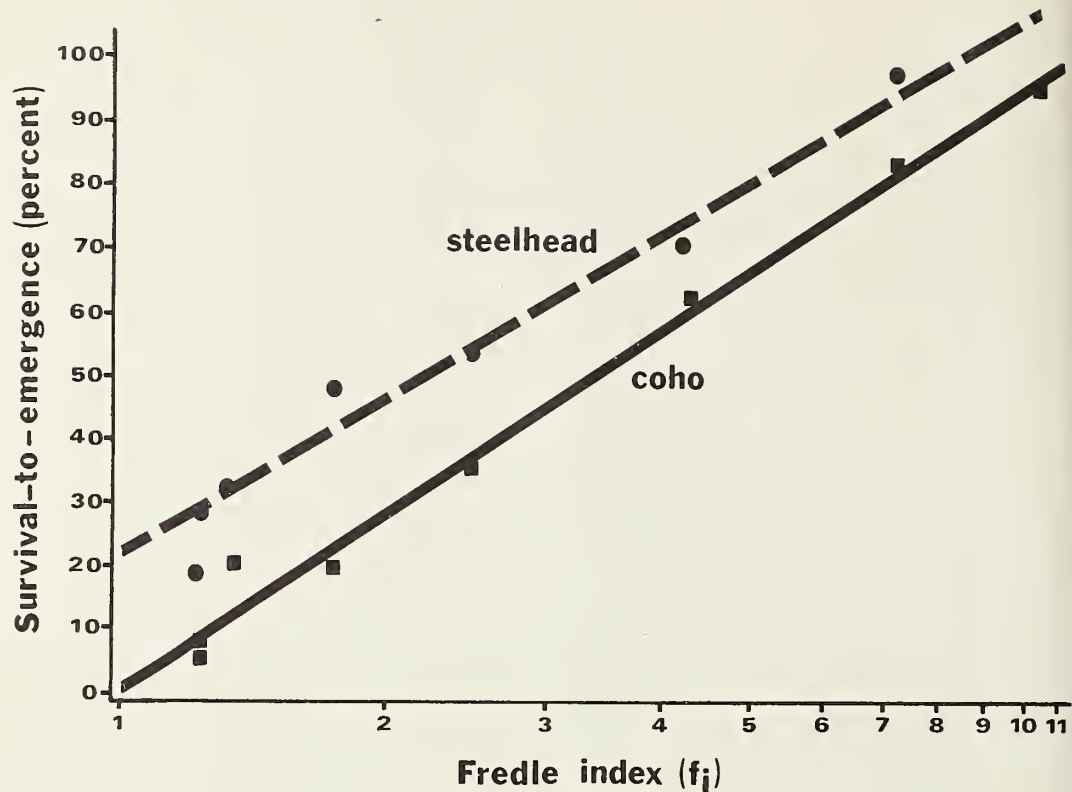
Figure 3.--Relationship between fredle index (f_i) numbers and survival-to-emergence of coho salmon and steelhead trout (semilog plot, lines fitted by eye; based on data of Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish Soc. 104(3):461-466).

Application

This method of calculating a quality index (f_i) for stream sediments allows biologists and land managers to identify the quality of gravel used for reproduction by anadromous salmonids. Also, comparisons can be made of gravel quality within and between streams, and temporal changes in texture and permeability can be monitored. The technique should be especially useful for measuring changes in gravel quality resulting from sedimentation from nonpoint sources in managed forest watersheds.

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